International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

FPGA Based Wireless Control System for Robotic Applications

Khushbu Lalpuriya[1], N. Ravi Prakash[2], Naveen Rastogi[3]
[1]*VLSI and Embedded system design, Gujarat Technological University, Ahmedabad*
[2,3]*Institute for Plasma Research, Gandhinagar*

***Abstract*— Robotic applications are much more needed and almost mandatory requirement in today's fast moving industrial economy. In these circumstances the development of Robotics is also taking up the speed with the help of various technologies directly or indirectly suitable for robotic applications. FPGA takes advantage over microcontroller due to its hardware based parallel architecture. Motors are one of the core part of the Robots and controlling them with FPGA is little tricky. FPGA based wireless interface is used to remotely control robotic applications. For that FPGA based PWM signal generation method is used. Code can be made in such a manner so that multiple parts (motors) can be controlled at a time. The ports availability also provides flexibility to extend the support for the number of motors or any Data acquisition mechanism. A user friendly wireless interface is developed to control robot remotely.**

***keywords*— FPGA, multiple motors, parallel architecture, PWM signal, robotic applications, wireless interfaces**

I. INTRODUCTION

In the fast growing world, real time controlling of any robotic application is very important. The idea behind developing the system is to make a single control system to control multiple robotic applications simultaneously because individual controller for every application is very difficult to synchronize and development of logic for every different application is also very time consuming. So the system is to be developed such that it can control any robotic application from remote area simultaneously in real time. Communication interfaces are also to be developed using which user can easily control any application remotely. The whole control logic should be inside the system, so the selection of controller is important. It should be such that it contains large number of memory storage inside it, so more numbers of logics can be added within it.

For general applications, microcontroller is good enough but critical applications would need real-time processing that is time critical. In this case, FPGA would be the best solution.

FPGA are used for time critical applications like real time multi motor control in robotic arms, any multi-motor precision application or any parallel processing application. In order to accomplish more work, more logic circuits can be added. FPGA get used ispecifically to do tasks a microcontroller cannot do efficiently, such as highly parallel or low latency operations, operating in multiple clock domains, or doing custom logic at hardware speeds. For these all reasons, FPGA is used to develop a control system.

Spartan 3E FPGA board is used for system implementation. Xc3s500E chip is used inside the board. Kit contains on-board 50 MHz clock oscillator. For experiment, two 9-pin RS-232 ports (DTE- and DCE-style), 10 user-I/O pins, two-input SPI-based Analog-to-Digital Converter (ADC) with programmable-gain pre-amplifier and 8 LEDs are used . More details about kit are given in datasheet of Xilinx Spartan3E user manual [2].

To control robot remotely, wireless module ZigBee Pro is used which works on ISM (Industrial, scientific and Medical) band. It works on IEEE 802.15.4 standard. The modules operate within the ISM 2.4 GHz frequency band. Data rate to transmit the data is 250 kbps. It has indoor range of 100 m and outdoor range of 1500 m which is sufficient for robot control. More details of the module are given in ZigBee manual [7]. Wireless module is interfaced with the Spartan 3E FPGA board to control the applications.

Work process flow and description of main modules are given in the subsequent topics.

II. PROCESS FLOW

The main concept to build the system is to generate a logic inside FPGA for proper selection of address signal and data signal to control any kind of robots simultaneously in robotic applications. Conceptual process flow is shown in the figure below which contains the required basic blocks. These blocks are generated in Verilog language to load the logic in FPGA chip. The details of process flow is described below:

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

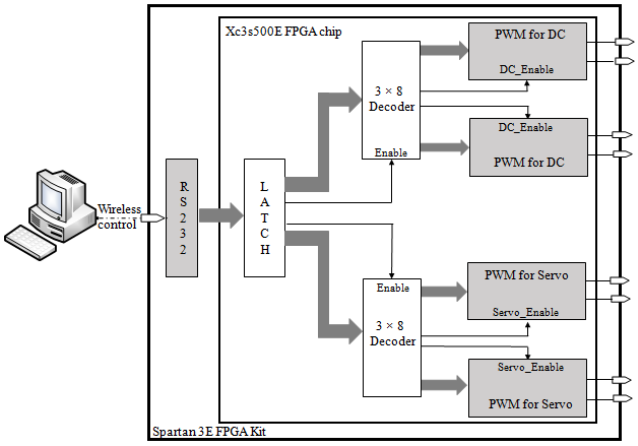

Fig. 1. FPGA based wireless control system

For ease of use, the data is sent from PC. For that, Serial interfacing is done which receives the data serially and convert it to 8 bit binary numbers. Received 8 bit binary numbers are stored in 8 bit latch. Here 8 bit latch is used to store the desired received data for further use. From 8 bit latched output, all bits are separated to access more number of ports using less control signal.

From 8 bits of latch, 3 bits go into 3to8 decoder as a data and 4th bit enables that decoder. Likewise, other 3 bits go into the other 3to8 decoder as a data and 8th bit enables that decoder. Output of the decoder is used to enable PWM module for DC motor and other signals are the input control signals to drive the DC motor. Other decoder's output is used to enable the PWM module for Servo motor and other signals are the input control signals. PWM modules have separate logic for DC motors and Servo motors. As per the user input, it can change the values of respective signals.

Main modules of the control system are described in next two sections.

A. Serial interfacing via RS232 protocol

Whenever any robot is to be remotely controlled through the PC via wireless module then serial interfacing is very important to communicate between them. In this experiment, to control the robot through PC, RS232 interfacing is done. Spartan 3E FPGA kit has on-board DTE and DCE DB9 port and RS232 voltage translator IC in the kit. The data signal is transmitted from PC and received by the FPGA chip using pin 2 and pin 3 of the DB9 connector respectively.

B. Wireless interfacing via ZigBee Module

To interface FPGA with robotic applications, wireless module ZigBee is used. Two modules are used in experiment. From two, one is Coordinator which works as transmitter and another is End device which works as Receiver. Coordinator is attached with PC and End device is attached with robotic application. Signal is transmitted to robot from PC through coordinator ZigBee and received by end device ZigBee. Robot is controlled as per the command given from PC and logic developed inside the FPGA chip.

Every key pressing of PC represents particular ASCII values which is transmitted through coordinator ZigBee and it is wirelessly received end device ZigBee. End device ZigBee sends the RS232 IC of FPGA board and it sends the data to the FPGA chip through voltage translator. FPGA has control logic of PWM signal generation module. So whenever respectively key is sent through the PC, it will be received by FPGA chip and will be sent to robot from the digital I/O port. Any action/movement can be given to robot by changing just the logic in the FPGA. Using this concept, any robot can be controlled by FPGA through wireless module.

C. PWM signal generation module

PWM is abbreviation of Pulse Width Modulation. It is also known as the duty-cycle variation method. This method is commonly used in speed control of motors. "Pulse" is meant by an electromagnetic wave or modulation. "Width Modulation" is meant by to adjust to or keep in proper measure or proportion the width of the pulse with respect to the frequency of the wave. The duty cycle is defined as the percentage of digital 'high' to digital 'low' plus digital 'high' pulse-width during a PWM period.

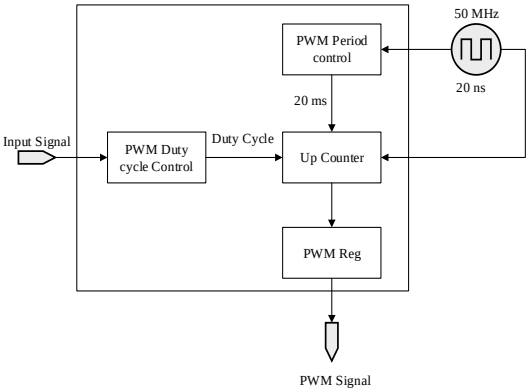

Fig. 2. Block diagram of PWM module

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

Fig. 2 shows the block diagram of PWM module which is developed inside the FPGA to drive the motor with the help of driver circuit. The architecture of the PWM part of the module consists of two registers, an up counter and on board clock. One of the two registers is to hold the PWM duty cycle value, which is the ratio of ON/OFF time determining the PWM waveform. The other register is to hold the PWM period data, which controls the duration of a complete ON/OFF cycle. The values in the two registers are accessible via serial interfacing and can be updated.

Up and down counters are used to count only when enabled and the Toggle flip flop toggles every time there is a final count from any of the enabled counters. When a data is loaded in the duty cycle register, the down counter begins to count down from high value to zero. When it crosses zero, the final count goes high, which toggles the PWM output to high. Every time the final count goes high it triggers the duty cycle value to be re-loaded and the Up-counter is enabled and the value is counted from zero to the high value. Once the Up-counter reaches the final count, it again triggers the flip-flop to toggle the PWM output. When a particular duty cycle value is loaded into the register, the PWM module will generate the corresponding PWM signal and send it through the on-board General Purpose Input Output (GPIO) pin. These PWM signals are then given to drive the motor.

III. IMPLEMENTATION

We have used Xilinx Spartan 3E board and Xilinx development tool ISE (Integrated Software Environment) to design the control logic and conducted experimental test. All the modules are generated in Verilog language. The experimental test verified the functional correctness of the hardware module.

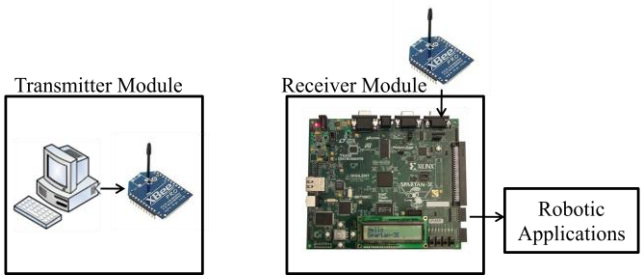

Fig. 4. Experimental Set up

Fig. 4 shows the overall system configuration of the experimental setup and Spartan 3E FPGA board is the central piece with wireless end device module and robotic application with required motor driver circuit attached. The board has a XC3s500E FPGA chip on it The GPIO pins on the board are directly connected to the FPGA device.

PWM module is implemented inside the FPGA chip in such a way that it can directly access the GPIO pins, and thus through the driver card, it drives robot. H-bridge circuit is used as DC motor driver circuit. The PWM outputs from the GPIO pins are fed into the H-bridge and then to drive a DC motor of robot.

The FPGA designs are implemented in Xilinx ISE software, which provides a variety of performance analyses, including resource utilization, speed, and power consumption. The Xilinx performance report is based on simulations of the hardware design. The interconnection of PWM module with the FPGA chip has clock frequency of 50 MHz . However we can change the clock across various frequencies in simulation to investigate the effects on module performance. The timing analyzer of the ISE software provides accurate information on delays from various points, nets and pads inside the FPGA.

The simulation waveforms are measured with the help of simulation tool and the results show that as per the command given, signals can be properly selected and addressed to the particular output port with 40ns delay. Here for DC motor selection, when '1' and '0' are pressed then it gives forward output to respective output channel. Likewise for '0' and '1' , gives reverse output to respective channel.

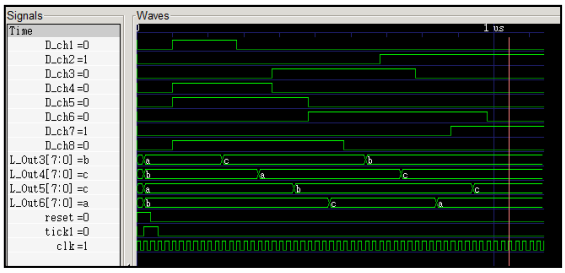

Fig. 5. Simulation result for multiple DC motor control

Output port of FPGA is connected to Digital Signal Oscilloscope before directly applying to motor. As shown in the waveform first two channels are for one DC motor which is in forward direction and last two are for second DC motor which is in reverse direction. Here medium speed is selected by applying 50% duty cycle.

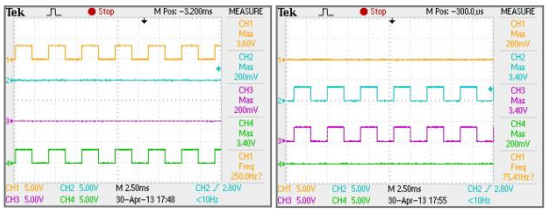

Fig. 6. Experimental waveform for DC motor logic

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

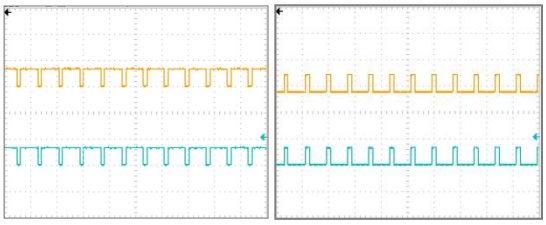

Fig. 7. Experimental waveform for DC motor control

As shown in the waveform, two DC motors are simultaneously driven from a applied logic in FPGA. Here logic is tested by applying different speed controls.

Module is tested with robotic application. Module is tested with DC motor to test the control of the speed and direction. From experiment, the speed of the motor is varied as per the command given from the PC and the direction is also controlled. The precise control of DC motor can be checked by taking feedback from the encoder attached on the wheel of the DC motor.

Module is tested with the servo motor to test the angle control. From experiment, the angle of the motor is varied as per the command given from the PC and the direction is also controlled. Angles of the robotic application with servo motors is tested as shown below:

Table 1
Experimental servo angles

Angle to be controlled	Required PWM signal
0°	1 ms
45°	1.25 ms
90°	1.50 ms
135°	1.75 ms
180°	2.00 ms

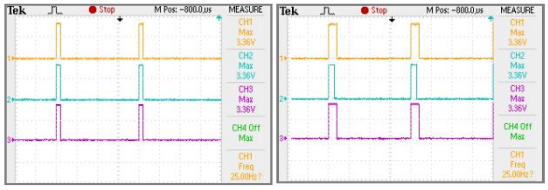

Fig. 8. Experimental waveforms for servo motor control

As shown in the first waveform, three servo motors are controlled at the same angle and in the second waveform, two motors are controlled at same angle and the third is at different angle.

IV. Conclusion

In this paper, FPGA based real time control system is developed for wirelessly control any type of motors in robotic applications. Addressing of control signals and sending data to particular signal are implemented in this paper. Hardware module is developed to generate PWM output pulses, which are the basic building blocks to drive robots. With the use of communication interfaces provided, all modules can be easily accessible. ZigBee and FPGA interfacing was also successfully developed. Functional verifications are done by applying the logic on the robotic applications. This work was the prototype of a big system. By applied logic, total 16 motors can be controlled but by taking advantage of FPGA, more number of logics can be added into the developed control system.

Acknowledgment

This work is carried out in Institute for Plasma Research as a part of Dissertation work of Master of Engineering under guidance of Mr. N. Ravi Prakash. I am very thankful to Institute for Plasma Research for giving me opportunity to work.

REFERENCES

[1] Samir Palnitkar, "Verilog HDL, A guide to digital design and synthesis", SunSoft press 1996
[2] Xilinx, "Spartan-3E FPGA Starter Kit Board User Guide", UG230 (v1.2) January 20, 2011
[3] Narashiman Chakravarthy, Jizhong Xiao, "FPGA-based Control System for Miniature Robots" IEEE/RSJ International conference on Intelligent Robots and systems, October 9,2006
[4] National Instruments, "Pulse Width Modulation using NI-DAQmx and LabVIEW", May10, 2010
[5] Tim Bennett and Vincent Rosa, "Speed control of DC motor using Pulse width modulation", Data Acquisition and Control Systems, Spring 2009
[6] "Servo motors control & Arduino", Future Electronics
[7] MaxStream, Inc. "XBee™/XBee-PRO™ OEM RF Modules", October,2010